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Water

W. V. MORRIS

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"Best of all things is water"
"Olympia II" — Pindar

Inland Waters Branch
DEPARTMENT OF ENERGY,
MINES AND RESOURCES
OTTAWA, CANADA



Foreword

A great deal has been said over the last few years about the importance of water, particularly its importance in rapidly-developing modern communities. Much of this recent interest springs directly from the fact that some of these communities, careless and improvident in their stewardship of clean water, have realized too late that the water they need to stay alive must now be purchased at an extremely high price, either by cleaning the water they have poisoned or by importing clean water from elsewhere — if indeed it can be obtained at all.

Canada is fortunate in its resources of fresh water, but most Canadians have little cause for pride in the stewardship of these resources. We, no less than others, despoil our streams and lakes with the untreated effluents of home and factory, blind to the realization that water can be polluted beyond the capacity of nature to restore it.

Pollution, admittedly a matter of serious concern, is only one of the many complex problems in water development and management. The nature of these problems is such that they will not be resolved by a piecemeal approach. A workable solution demands the type of concerted approach which involves governments at all levels as well as the many other organizations concerned with water development and management.

But even the best efforts of responsible agencies will fall short of success if they are not backed by the support and understanding of an informed public. This publication attempts to contribute to a better understanding of what is involved in the wise development and management of our priceless heritage of fresh water.



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Geological Survey of Canada: page 18

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Water



Water is essential to life. Without it, neither man himself nor the animals, fish and plants upon which he depends for food could survive. A man must drink 5 to 6 pints of water every day. More than 70 per cent of the human body's weight is made up of water and unless the daily losses from this supply are replenished, the body cannot continue to function.

Beyond these fundamental requirements of life, it is difficult to think of any item used by man which does not, at some stage of its creation or manufacture, depend upon water.

In early civilizations (and even today in some primitive societies), 3 to 5 gallons a day for each person for drinking, preparing food, and washing, would provide a minimum level of comfort. But as standards of living increase and civilization and technology advance, requirements for water mount. Today, in Canada and in the United States, the average self-contained household uses from 20 to 70 gallons a day for each person. The higher figure includes extensive lawn and garden sprinkling and automatic washing machine operation.

For each of its citizens, a modern city uses one to two hundred gallons a day. The more industrially developed a city becomes, the more water it uses,

because industry places heavy demands on water supplies.

The relationship between standard of living and consumption of water is illustrated in the United States, where some 1,400 gallons are used each day for every man, woman, and child. Less than 10 per cent of this amount is used by individuals in their own households. The greater part is used by industry and agriculture; the demands for irrigation slightly exceed those of industry.

The extent to which modern society depends upon water is apparent in the variety of ways in which water is used. Perhaps the most obvious is the domestic requirement for drinking, cooking and washing. In industry, it is used for cooling, boiler feed, plant sanitation and as a direct part of many manufacturing processes. The energy of falling water is harnessed to drive the generators which supply electric power for homes, farms and industry. Transportation by water is still the most economic means of moving bulky materials. In agricultural operations, adequate water, either by direct natural supply or by irrigation, is vital. The harvest of fish from lake and river contributes to the national economy. Water provides the means of diluting and carrying away wastes. And in recreation, water-oriented activities are becoming increasingly popular.



The World's Water

The water in the world today was here when the earth was born. The earth's estimated 326 million cubic miles of water has remained unchanged in quantity throughout the four or five billion years of its existence.

When the earth was very young, practically all its water was in the form of vapor. At first, the earth's surface was too hot to accept water. Any that fell was immediately reconverted to steam, and the slowly-cooling earth was enveloped in thick layers of cloud.

After many thousands of years, the earth's surface cooled sufficiently to retain the rain which fell. Year after year, century after century, it rained. The constant, unremitting deluge began wearing away and dissolving rocks and minerals and carrying the dissolved material into the ocean basins.

The early ocean on the young earth was not very saline. But the dissolved materials carried from the continents made the sea ever more salty. Water evaporating from the sea returned to the atmosphere, fell again as rain, flowed over the continents, through the rock mantle, in a continually recurring cycle. This inexorable process

UNITS OF MEASUREMENT

The units of volume used in this publication are gallons, cubic feet, and cubic miles.

In most municipal and industrial uses, quantities are calculated in gallons. A gallon (Imperial) is, by definition, the volume occupied by 10 pounds of water.

The flows in Canada's rivers are generally measured in terms of cubic feet. A cubic foot of water weighs about 62½ pounds, and is, therefore, equivalent to 6¼ gallons.

In describing the vast quantities of water on and in the earth, a much larger unit — the cubic mile — is used. Another unit of volume in common use is the acre-foot — the volume of water which would cover an acre to a depth of one foot.

Many countries use the metric system of measurement and in these countries the basic unit of volume is the cubic meter.

The following table shows equivalent volumes in these various units.

| Cubic Miles | Acre Feet | Cubic Meters | Cubic Feet | Imperial Gallons* |
|-------------|-----------|---------------|-----------------|-------------------|
| 1.0 | 3,379,200 | 4,168,260,100 | 147,197,952,000 | 919,987,200,000 |
| | 1.0 | 1,233.50 | 43,560 | 272,250 |
| | | 1.0 | 35.31 | 220.1 |
| | | | 1.0 | 6.24 |

*One Imperial gallon = 1.20 U.S. gallons

Some useful equivalents relating to flow are:
1 cubic foot per second = 375 gallons per minute.
1 cubic foot per second = 540,000 gallons per day.
100,000 cubic feet per second = 21.4 cubic miles per year.

continued to add to the salinity of the sea, to the point where today every gallon of sea water contains, on the average, more than a third of a pound of dissolved salts.

One hundredth of one per cent of the world's water sustains earth's total population

Of the estimated 326 million cubic miles of water on earth, about 317 million cubic miles or 97 per cent, is contained in the oceans. An additional one million cubic miles of salt water is buried underground. Of the remaining 2.5 per cent which makes up the world's total supply of fresh water, some seven million cubic miles is frozen in the polar ice caps and in glaciers in various parts of the world. Ninety per cent of this ice is in Antarctica, and the rest is, for the most part, in the Greenland ice cap.

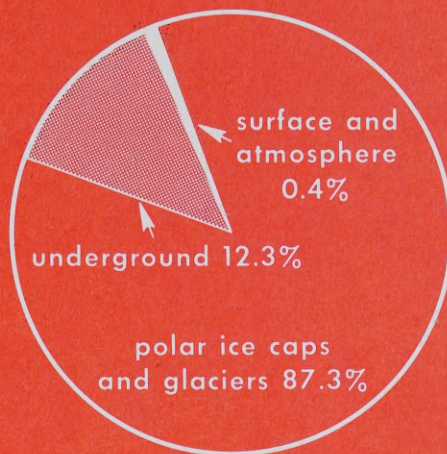
In addition to the underground salt water already mentioned, an estimated one million cubic miles of fresh water is buried beneath the surface of the continents.

These quantities — 318 million cubic miles of salt water, 7 million cubic miles of fresh water frozen into ice, and one million cubic miles of fresh water underground — account for practically all the earth's water. There is, however, a relatively small but immensely important fraction of the world's water supply — about one hundredth of one per cent — which is essential to life on this planet.

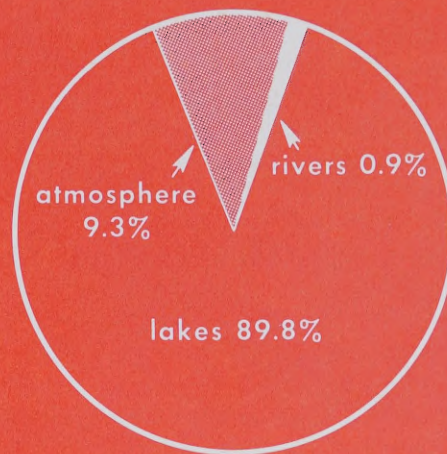
One hundredth of one per cent of the world's water sustains earth's total population.....



WORLD'S TOTAL WATER:
326,000,000 CUBIC MILES



FRESH WATER:
8,000,000 CUBIC MILES



SURFACE AND ATMOSPHERIC
WATER: 33,400 CUBIC MILES

This relatively small amount of water is estimated at 33,400 cubic miles. About 30,000 cubic miles is stored in lakes in various parts of the world. The remaining 3,400 cubic miles is present in the world's rivers and in the atmosphere at any given moment.

The world's fresh water supply is maintained by a gigantic natural distillation system

The most important feature of this 3,400 cubic

miles of water is not its quantity, but its *dynamic quality*. It is constantly on the move. It falls as rain or snow, it moves over the land surface, percolates below the surface, travels through the rivers and lakes, eventually returning to the ocean. But at every point in this movement, and from the ocean reservoir itself, some of the water is constantly being returned to the atmosphere as vapor, to move around the earth and fall again as rain or snow. This huge, never-ending cycle of distillation and circulation, so vital to life on this planet, is known as the "hydrologic cycle".

WATER—NATURE'S MOST VERSATILE COMPOUND

"Colorless, transparent, tasteless, scentless compound of oxygen and hydrogen in liquid state, convertible by heat into steam and by cold into ice."

This simple definition conveys little idea of the remarkable properties of the unique substance — water. Nor is water the simple chemical compound that is implied by the well-known formula, H_2O . It is true, as the formula indicates, that each molecule of water is made up of two atoms of hydrogen combined with one of oxygen. In 1934, however, a new kind of hydrogen with twice the weight of the normal hydrogen atom was discovered. This heavy hydrogen, called deuterium, in combination with oxygen, forms "heavy water", well known for its use in certain types of nuclear reactors. More recently, a third form of hydrogen, called tritium, triple the normal weight and radioactive, has been discovered. These different forms (called isotopes) of hydrogen atoms, produce different types of water. Deuterium oxide (heavy water) and tritium oxide (tritiated water) are found in all natural water, although in extremely small quantities (in fact tritiated water was virtually non-existent until man began exploding hydrogen bombs). The structure of water is further complicated by the fact that oxygen, like hydrogen, has three isotopes. Water is, therefore, actually a mixture of many different combinations of these isotopes.

Does this mean that the formula, H_2O , is obsolete? Not at all. Although water is not the single, simple compound it was once thought to be, the formula is still valid because all the isotopes have the same chemical behavior in their ordinary reactions, and the same chemical

symbol (although, for convenience, the symbols D and T are sometimes used to refer to deuterium and tritium). And by far the greatest number of water molecules are made up of normal hydrogen and oxygen atoms, bound together in the ratio two to one.

Most people would find little meaning in the statement that "the properties of water arise from the hydrogen bonding and the tetrahedral arrangement of electron pairs around the oxygen atom". What the statement means in simple terms is that the hydrogen and oxygen atoms in each molecule are bonded very strongly together — giving water its great chemical stability — and that adjacent molecules of water are also bonded strongly together. This strong bond between molecules (about one-sixteenth as strong as the bond between the hydrogen and the oxygen) gives to water most of its unique physical properties.

Most of these properties are well known; what is perhaps not so well known is the extent to which life on earth depends upon them.

Water in its solid form is lighter than in its liquid form (ice floats on water); it is almost the only substance with this property. Like other substances, water contracts as it cools. On freezing, however, it expands (in fact the change from contraction to expansion begins a few degrees above the freezing point). If this were not so, lakes and rivers would freeze upward from the bottom instead of downward from the surface. Fish could not survive in these circumstances, and it is unlikely that rivers and lakes in northern countries would ever completely thaw. The expansion which accompanies the freezing of

water and the great force exerted in that expansion, plays a large part in the breaking up of rock, the heaving of soil, and the wearing down of mountains.

Water has a large capacity for absorbing heat without a great rise in temperature as anyone who has waited for a pot of water to boil is aware. Large bodies of water, therefore, can store immense quantities of heat. As a result, oceans and large lakes effectively reduce extremes of climate by acting as temperature moderators.

Water, when heated, evaporates very slowly compared with most other liquids (the physicist would say that water has a high heat of vaporization). Consequently, there is relatively little water lost to the air by evaporation when, for instance, overhead sprinklers are used for irrigation. The evaporation which does take place, however, produces a significant cooling effect — one which can be recognized by the swimmer leaving the water in even a light breeze. This property is used to advantage in industrial cooling where water is sprayed in cooling towers. In hot, dry climates, water is often kept cool by storing it in porous earthen jars. The small amount of water which seeps through the porous materials is evaporated from the surface of the jar, producing a significant cooling effect.

Water has a surface tension (ability to stick to itself) higher than any other liquid except mercury. The ability of a steel needle to float on water demonstrates this property. Water will adhere to certain other materials, the ability to do so depending upon the presence of oxygen in the chemical structure of the other material. Glass, clay, cotton, all of which contain oxygen, are examples of materials to which water will adhere. In clay soil, water tends to spread in a thin film and to cling to the surfaces of soil particles. On the other hand, water will not adhere to paraffin, which does not contain oxygen.

Adhesion, the attraction to other substances, and cohesion, or surface tension, the attraction to itself, combine to produce what is known as capillarity, the ability to rise in small, wettable tubes. It is capillary action which causes water to rise in a wick. This same property allows trees and other plants to draw water from the soil through small passages, to heights of over 400 feet. An extremely important effect of capillary action is seen in the ability of soil to hold water against the pull of gravity. Were it not for this effect, plant growth would be impossible.

Of all the many and varied properties of water, perhaps none is so remarkable as its ability to dissolve other substances. In this respect, it is outstanding among liquids. The ancient alchemists, searching for the universal solvent, overlooked the most obvious of them all. There is hardly a chemical element known which has not been identified in solution in the earth's waters. Some of these elements are dissolved in minute amounts only, but others are found in very significant quantities (sodium and chlorine, for instance, constitute most of the oceans' salt). Even a drop of rain water falling through the air dissolves many substances in its passage to the ground — nitrogen, oxygen and, where the air is polluted, carbon dioxide, nitric acid, ammonia and sulphur. Near the oceans, it also picks up and dissolves chlorides. When it reaches the earth, it continues to dissolve varying amounts of almost everything with which it comes in contact.

Were it not for the solvent property of water, life could not exist. It is the all-important agent which transfers within living animals and plants the compounds vital to life itself. In dissolving other materials, the water itself undergoes no chemical change whatever. A generally inert solvent, it is purified by evaporation or distillation, either natural or man-produced, and is ready to be used again.

If all the moisture in the atmosphere were suddenly precipitated onto the earth's surface, the layer of water formed would be no more than one inch thick.



Fresh Water

To live, man must have fresh water — for his own consumption and for the production of most of his food.

The entire story of man could be written in terms of his need for fresh water. The world's oldest civilizations — Egyptian, Sumerian and Harappan — flourished on lands made productive by great rivers — the Nile, the Tigris and Euphrates, the Indus. When water supplies failed, either by the vagaries of nature or misuse by man, civilizations perished.

An accurate assessment of the world's fresh water resources is essential

By far the greatest portion of the earth's water is unsuitable for consumption by man, animal or plant because it is either too salty or permanently frozen. No world-wide inventory of fresh water has ever been made. Before any attempt is made to solve the complex problems of water use on an international scale, there must be a reasonably accurate knowledge of the magnitude of the world's fresh water resources. Finding out how much water there is in the world and how it is distributed is one of the objectives of the International Hydrological Decade, a ten-year international program begun in 1965. This knowledge is an essential prerequisite to the beneficial use of water for all mankind.

Fresh water in the hydrologic cycle

In the absence of an accurate inventory, some estimates (and they are no more than that) have been made of the amounts of fresh water in the various phases of the hydrologic cycle.

Atmosphere. In the vast ocean of air surrounding the earth (roughly four times the volume of the world's oceans), the amount of water present at any time is surprisingly small. This water is mostly in the form of invisible vapor but part of it appears as visible cloud. If all the water in the atmosphere were suddenly precipitated onto the earth's surface, it would form a layer not more than one inch thick. The importance of this water, however, is not its quantity, but the fact that it is being constantly replenished. Water is continually being removed from the atmospheric storehouse and precipitated over the surface of the earth. The reverse process of evaporation from land and water surfaces and from plants returns an equivalent amount to the atmosphere. As a result, the atmospheric water content remains practically constant. Although at any moment there is only about 3,100 cubic miles of water in the atmosphere, the earth receives each year some 113,000 cubic miles of precipitation, 89,000 cubic miles on the oceans and 24,000 cubic miles on the land.

The 24,000 cubic miles of annual precipitation which falls on the earth's land surface averages



about 27 inches, (about the same, for example, as the yearly precipitation at Fort William, Ontario). It must be remembered, however, that precipitation is not uniformly distributed. There are vast desert areas where rain falls only rarely; on the other hand there are areas where the annual precipitation is as much as 400 inches or even more.

The amount of water evaporated from the oceans is on the average about nine per cent more than the amount which falls back to the oceans as rain. The difference represents the water vapor which drifts with the winds, to fall as precipitation over land areas. It is this precipitation which produces the flow of all the world's rivers.

Rivers. All river flow is the result of precipitation. This may be self-evident, and the passage from Ecclesiastes quoted on page 13 indicates that, even 2,000 years ago, this idea was not new. But surprisingly enough, men have had some very unusual ideas about the origin of rivers. In the Middle Ages, for example, people believed that the rivers flowed in some mysterious way from the center of the earth. It was not until late in the 17th century, in fact, that Halley in England, and Perrault and Mariotte in France, made some measurements and calculations, and discovered that the amount of water flowing in rivers, after allowing for evaporation, was approximately equal to the amount of water falling as rain and snow on the area drained by the rivers. This concept,

THE HYDROLOGIC CYCLE

The hydrologic cycle is a world-wide natural circulation system in which water is evaporated from the earth's surface (from oceans, from other large bodies of water and from land areas) condenses to form cloud and is returned to the earth as precipitation.

Evaporation is a continuous process, particularly from the ocean surface. A large part of the evaporated moisture condenses and is returned directly to the oceans as precipitation. A considerable portion, however, is carried over land areas by the winds where it is precipitated as rain, snow, sleet, or hail. A relatively small amount may condense as dew or frost. Nearly all of this dew or frost is either evaporated directly or is absorbed by plants and returned to the atmosphere by transpiration.

The moisture which falls over the land as precipitation may follow any of a number of courses. Some of it is re-evaporated before it reaches the ground. Some may be intercepted by vegetation, by buildings or pavements, and part of this intercepted precipitation may be evaporated directly. Part, however, infiltrates the ground and part runs off into stream channels, to be carried to the ocean.

In its passage to the ocean, water is evaporated from the surface of the stream, particularly if there are large lake areas along its route. Water can also be lost from the stream by seeping out of the channel to become groundwater.

Of the water which enters the ground, either by direct infiltration or through the banks or beds of streams, part is stored near the surface where it is evaporated to the atmosphere or used by vegetation and returned to the atmosphere by transpiration. Another portion joins the groundwater, and may find its way to streams, or appear

at the surface in springs, or travel through the ground to the ocean.

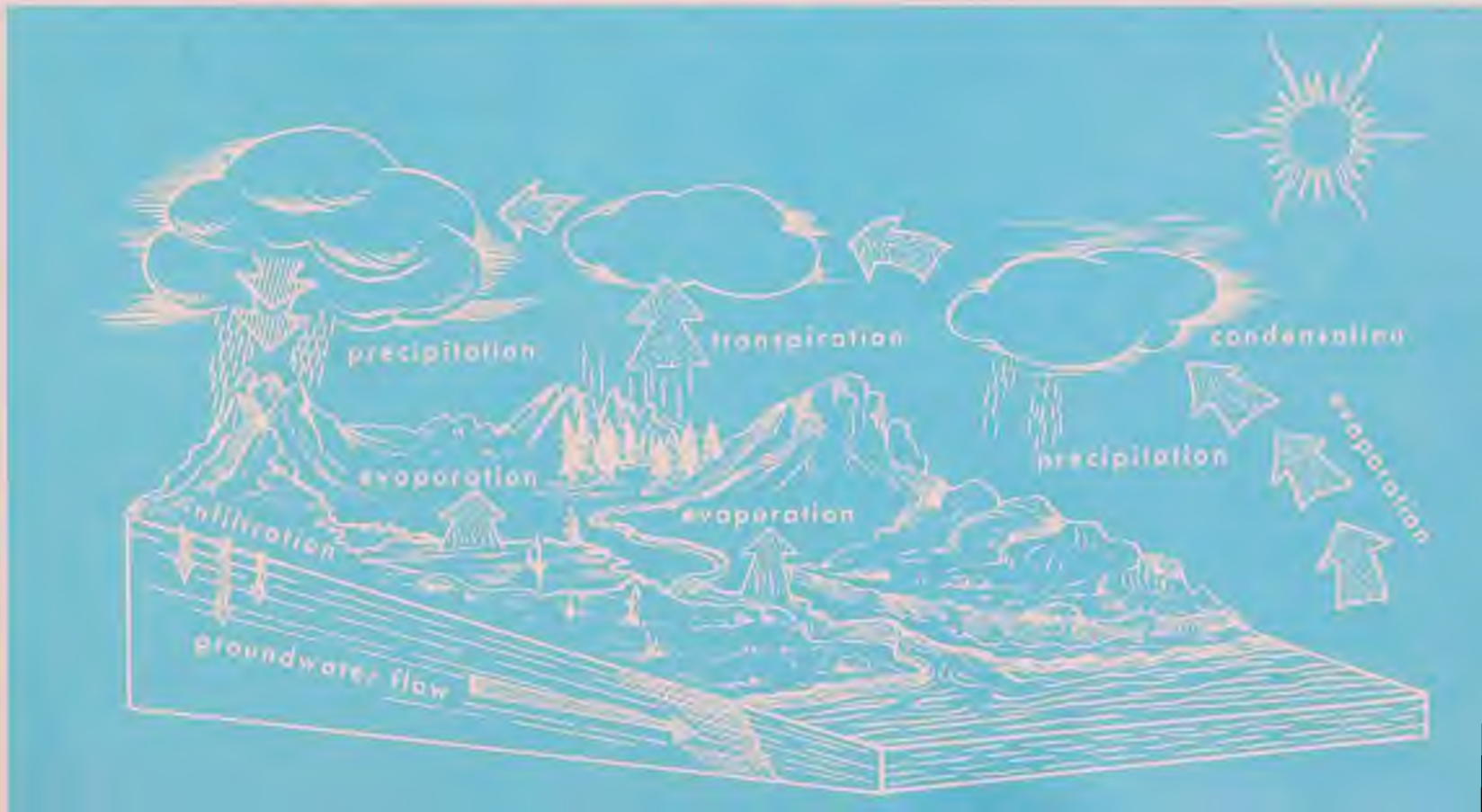
On the way to the ocean, there may be an interchange, in either direction, between streams and groundwater.

Although the basic cycle is simple in concept — ocean to cloud, to land, to river, to ocean — it is obvious that, with the many alternative routes water may follow in every phase of the cycle, the analysis of the hydrologic cycle can be an extremely complex task. The science which is devoted to a study of the cycle is called hydrology.

*"All the rivers run into the sea;
Yet the sea is not full;
Unto the place from whence the rivers come,
Thither they return again."*

Ecclesiastes 1:7

THE HYDROLOGIC CYCLE





The amount of water contained in all the rivers of the world is relatively small — hardly enough, at any given instant, to fill Lake Ontario. Much more important than the actual **quantity** of water in the river at a given moment is the **flow** of water in the channel.

revolutionary at the time, is now accepted universally as a matter of scientific fact.

Each year, the rivers of the world pour about 8,400 cubic miles of water into the sea. This represents an average flow of nearly 40,000,000 cubic feet every second. The total flow in Canada's rivers amounts to about 3,500,000 cubic feet per second, which is a little less than 9 per cent of the world's total. The world's largest river, the Amazon, has an average flow of 7,500,000 cubic feet per second, nearly one fifth of the world's total. No other river even approaches this. The Congo, second to the Amazon, has an average discharge of only 1,400,000 cubic feet per second, less than one fifth the flow of the Amazon.

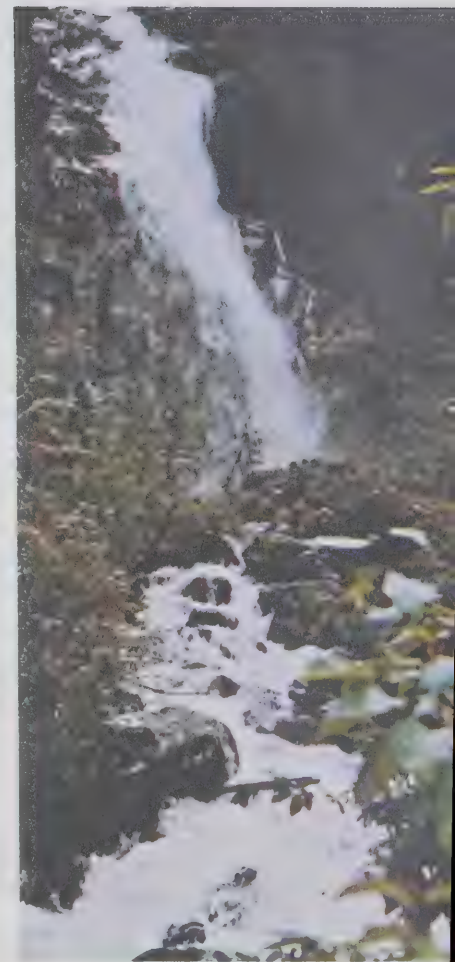
The North American continent's largest river, the Mississippi, has an average flow of 630,000 cubic feet per second. The St. Lawrence, Canada's largest, discharges some 400,000 cubic feet per second.

Notwithstanding the importance of rivers in world history and their importance for the future, the amount of water contained in the world's rivers is relatively small. If it were possible to pool all the water which, *at any given instant*, is contained in all the rivers of the world, the lake formed would be a little smaller than Lake Ontario. The importance of rivers is related, not to the actual *quantity* of water in the channel at a given moment, but to the *flow* of water.

Since this flow is produced by precipitation, and since precipitation is neither continuous nor uniform, the flow of a river is continually fluctuating. Consider, for example, Canada's Fraser River. The mean flow of the Fraser River, calculated over the period during which it has been measured at Hope, British Columbia, is about 94,000 cubic feet per second. In the year 1959-60, however, it produced a mean flow of 115,000 cubic feet per second, and in 1928-29 its mean flow was only 67,500 cubic feet per second.

Then again, in the course of a year, a river's flow fluctuates from day to day and from month to month. The Assiniboine River, for example, has a mean flow at Brandon, Manitoba, of 1,150 cubic feet per second measured over the past fifty years. During the year 1923, however, its flow varied from a low of 182 to a high of 23,000 cubic feet per second. The peak flow is twenty times the long-term mean. All rivers do not fluctuate as widely as this. The maximum recorded flow of the St. Lawrence River at Montreal amounts to only about twice its minimum flow.

Fluctuations during the year are partly the result of variation in precipitation and evaporation over the drainage basin, and the fact that much of the annual precipitation, occurring as winter snow, is held in a frozen state until the spring thaw, but there are many other factors which affect the flow. The size and shape of the drainage basin, the topography, the nature and extent of vegetation,



The importance of lakes lies in their ability to store water, allowing rivers to survive through periods of low precipitation.

the type and condition of the ground surface, all influence not only the rate at which precipitation reaches the river but also the percentage of precipitation which finds its way to the river.

No two rivers are exactly alike in their characteristics. But all of them, from the smallest brook to the mighty Amazon, form a vital link in the hydrologic cycle.

Lakes. The lakes of the world contain practically all the fresh, liquid, surface water in existence — about 30,000 cubic miles of it. Nearly one fifth of this (an estimated 5,500 cubic miles) is in the Great Lakes of North America. The large lakes of Africa — Nyasa (Malawi), Tanganyika, and Victoria — together contain an estimated 8,700 cubic miles, 29 per cent of the world total, and Russia's Lake Baikal, deepest lake in the world, contains over 6,300 cubic miles, about 20 per cent of the total. Together, these nine lakes contain about two thirds of the world's fresh surface water. The remaining third is distributed in hundreds of thousands of smaller lakes in all parts of the world.

Canada probably has more lake area than any other country in the world. In size, Canada's lakes range all the way from Lake Superior with a surface area of 31,800 square miles (11,100 square miles of which is in Canada, the remainder in the United States) through such lakes as Great Slave Lake (11,000 square miles) and Lake Winnipeg (9,500 square miles), down to the myriad tiny





lakes, many of them unnamed, with areas less than a square mile.

Lakes have been defined simply as wide places in rivers and, although it may be an oversimplification, this definition is essentially true. The importance of lakes rests in their ability to store water, allowing rivers to survive through periods of low precipitation.

Compare, for instance, the St. Lawrence River with the Saskatchewan River. The Saskatchewan River, whose mean flow at The Pas, Manitoba, is 23,700 cubic feet per second, has recorded a maximum flow of 105,500 cubic feet per second and a minimum of 1,790 cubic feet per second. The maximum recorded flow is $4\frac{1}{2}$ times the mean flow and 60 times the minimum. The St. Lawrence, on the other hand, with a mean flow at Cornwall of 246,000 cubic feet per second, has recorded a maximum of 317,000 and a minimum of 164,000 cubic feet per second. The maximum is only 1.3 times the mean and 1.9 times the minimum.

The difference in flow patterns in these two rivers is to some extent the result of a difference in precipitation distribution, but it is mainly due to the vast storage provided by the Great Lakes in the case of the St. Lawrence, compared with the almost negligible lake storage on the Saskatchewan River. Variations in precipitation and in rates of snowmelt are reflected in the flow of the Sas-

katchewan, but similar variations are absorbed in the huge natural reservoirs of the Great Lakes.

Storage of this kind is so valuable that man has spent billions of dollars throughout the world, building dams and control works to improve nature's controls in existing lakes, or to create new lakes whose storage can be artificially controlled. Thus Lake Superior and Lake Ontario, the highest and the lowest respectively of the Great Lakes, are controlled by dams at their outlets, so that the natural storage can be more usefully employed. Similarly, Russia's huge Lake Baikal is controlled by the Irkutsk Dam on the Angara River.

Throughout the world there are many examples of lakes created by man to provide storage where little or none existed naturally. A few of these are Lake Mead in the United States, with a volume of about 9 cubic miles, created by the Hoover Dam; the lake behind the Kariba Dam in Africa, with a volume of 39 cubic miles; and in Canada the lake behind Kenney Dam on the Nechako River in British Columbia, with a volume of about $5\frac{1}{2}$ cubic miles, and the recently-formed Lake Diefenbaker, created by the Gardiner Dam on the South Saskatchewan River at Elbow, Saskatchewan.

Several other man-made lakes are now being created in Canada to store water for various purposes. In British Columbia, the huge Portage Mountain Dam on the Peace River will create a lake with a volume of 25 cubic miles; and in the Province of

It is impossible to estimate accurately how much fresh water is buried beneath the ground, but there is no doubt that it is many times greater than all the fresh water on the earth's surface and in the atmosphere.



Quebec, the Manicouagan 5 Dam, one of the largest and most massive buttressed, multi-arch dams in the world, will impound 34 cubic miles of Manicouagan River water.

Man-made or natural lakes are important, not only because they contain most of the world's fresh surface water, but because they perform an extremely valuable task in regulating the flow of many of the world's rivers.

Underground. Beneath the surface of the earth there exists a virtually untapped reservoir of fresh water. It is impossible to estimate accurately how much water is buried beneath the ground, but there is no doubt that it is many times greater than all the fresh water on the surface and in the atmosphere. Very rough estimates place the amount at 2 million cubic miles. Half of this amount is probably located within half a mile of the earth's surface; the rest is deeply buried, perhaps down to 5 miles below the surface. This deep water is not easily recoverable, and may be fairly saline.

The knowledge that fresh water reservoirs exist beneath the earth's surface is not new. The Old Testament, in describing the Exodus, which took place over 3,000 years ago, contains many references to wells and to water under the earth. Genesis, still earlier, has similar references. It is only fairly recently, however, that even a vague approximation of the extent of underground water

has been made. The estimated one million cubic miles in the upper half mile of the earth's mantle is enough to supply all the world's rivers for over one hundred years.

The term "groundwater" is applied to the water under the earth in the zone where all the pores in the containing material are saturated. The upper surface of this "zone of saturation", called the "water table", is found at varying distances below the ground, and in some places, right at the surface.

Above the water table is the "zone of aeration" where water is present, but where the pores also contain air. There is, at any moment, an estimated 16,000 cubic miles of water in the zone of aeration.

Although water cannot be extracted from the zone of aeration by wells, the zone of aeration is nevertheless extremely important. First of all, it includes the soil zone, which supplies food and moisture to plant growth. Life on earth, which depends on this plant growth, could not exist were it not for the soil zone, and the constant replenishment of soil moisture to replace that absorbed by plants. Secondly, the zone of aeration is important because it acts as a filter for water passing through it. Practically all groundwater is derived from precipitation, and to reach the zone of saturation, it must filter down through the upper layers of soil and rock material which make up



the zone of aeration.

There are, of course, other sources of groundwater — water rising from the earth's interior, as in some areas of volcanic activity; water trapped in sediments when they were deposited perhaps hundreds of millions of years ago; water produced by chemical reactions beneath the earth's surface. This water, however, is usually too mineralized for most uses. In general, it is true to say that any *usable* groundwater is part of the circulation pattern of the hydrologic cycle.

It is very important to realize that groundwater is not static. There is a natural movement of water through groundwater reservoirs, from the recharge area to the areas of natural discharge. This movement is very slow (where surface water velocities are described in feet per second, groundwater velocities are measured in feet per day, or even feet per year). As the groundwater moves slowly through the minute subterranean channels in fractured rock or between granular particles, it may be intercepted by wells drilled along its route, or it may continue until it reappears naturally in a surface spring or by seepage, or it may be discharged into a watercourse where it can help to maintain streamflow during long dry periods. In this slow movement of water from the surface, down through the zone of aeration, into the groundwater reservoir, and through the reservoir to the point of eventual discharge, the main moving force is gravity. Water may be pulled up-

INTERNATIONAL HYDROLOGICAL DECADE

During the past one hundred and fifty years, the population of the world has expanded at a truly remarkable rate. Accompanying this expansion, in some parts of the world at least, has been a significant improvement in living standards. The population growth and the rise in living standards have combined to impose a demand upon available fresh water supplies that in certain regions of the world has assumed serious proportions.

On the other hand, there are parts of the world which, so far from suffering water shortages, are plagued with the problem of recurring floods — floods which are frequently serious enough to cause loss of life and heavy damage to property.

What the world is faced with then is a problem, primarily of water distribution — not enough water in one place, too much in another. But there is also the question of how long the earth's supply of fresh water will be adequate to sustain a growing world population. It has to be remembered that the total supply of water in the world is no more than it has ever been — it does not increase.

Any nation, if it wants to, can find partial answers to its own water supply problems, but because water, in its passage through the hydrologic cycle, pays no heed whatever to political boundaries, the only satisfactory approach to effective solutions is through co-operation among nations. The whole business of water management, particularly on a global basis, is so complex that only through a concerted international effort by scientists in all parts of the world will principles be developed

which can be applied to all aspects of the hydrologic cycle in the varied climatic regions of the globe.

It was with this concept in mind that the United Nations Educational, Scientific and Cultural Organization launched on January 1, 1965 the International Hydrological Decade, a ten-year program of study and research into the fundamental principles affecting water distribution and movement throughout the world.

One of the objectives of the program is to determine the actual amount of fresh water available in the world. But this information is only of limited value without a thorough understanding of the complex operation of the hydrologic cycle, through which moves all the fresh water which sustains life on earth. Once the complexities of the hydrologic cycle are understood, specialists can then approach the more critical problem of how and to what extent the operation of the hydrologic cycle can be manipulated to smooth out the frequently erratic pattern of droughts and floods.

The program is so vast in scope that the opportunities which it will provide for education and training in hydrology and associated sciences are enormous. This in turn will contribute effectively to each nation's ability to solve its own water problems and lead to greater public awareness of the value of wise water management policies. The ten-year program will also help to provide the technical knowledge which is of vital importance if the world's fresh water supply is to be used for the benefit of all mankind.

Canadian Participation

Canada is taking a very active part in the IHD program for two reasons. First, this country, in common with all the other participating countries, stands to gain considerably in experience and knowledge from participation in an international program of this kind and secondly, Canada is in a unique position to contribute to the success of the venture. Where, in many other countries, climatic conditions and physical topography combine to form hydrologic environments which vary little across the entire region, here in Canada the hydrologic environments vary from arctic to temperate and very humid to semi-arid. There is also the very important fact that, because Canada has within its boundaries a considerable portion of the world's total supply of fresh water, any international program of research into water supply and movement could be grossly in error without Canadian participation.

The wide range of climatic environments found in Canada offers unparalleled opportunities for studies in comparative hydrologic patterns. In each of these hydrologic regions, basic and applied research is being carried out on representative and experimental basins, the air-land interface, surface runoff, water quality, soil moisture, groundwater, lakes, snow, ice, glaciers, geomorphology, and the influence of man's activities on the hydrologic cycle.

In recognition of the scope of the proposed Canadian program and in anticipation of the contribution that this country would offer, Canada was appointed to a two-year term (1965-1966) as a member of the Coordinating Council for the IHD, later extended for a second two-year period.

ward by capillary forces or, close to the surface, by solar energy, to be returned to the atmosphere by evaporation from the soil or by transpiration from plants (in some desert basins, all the water that falls as precipitation may be dissipated in this way with the result that groundwater reservoirs in these areas may be recharged only a few times in a century). Once the water has descended below the root zones of plants, however, it is beyond the sun's influence and its movement is caused mainly by gravity.

The vast supply of fresh water stored underground is important for two reasons. First, it performs a valuable function as a supplier of streamflow, producing, in fact, the entire flow of some streams during dry periods. Of equal importance, it constitutes a valuable source of supply for individuals, communities, industries, and irrigated farms in many parts of the world, the water being obtained directly by the use of wells. In the United States, for example, it is estimated that close to 20 per cent of the country's water supply is obtained in this way. In Canada, about 10 per cent of the country's supply is derived from groundwater.

Ice and snow. A tremendous quantity of fresh water — an estimated 7 million cubic miles of it — is permanently frozen in the polar ice caps. Far greater in quantity than all the liquid fresh water in the world, the fresh water locked up in the polar ice caps is as unusable as the salt water of the oceans.

An estimated 630,000 cubic miles of fresh water

Glaciers exert a direct influence on the hydrologic cycle, storing water in the form of ice and releasing it by melting to contribute to the flow of rivers.

is frozen into the Greenland ice cap, but by far the largest amount of the world's ice — about 90 per cent of the total — is located in the Antarctic ice cap. To attempt to visualize the amount of water frozen in Antarctica, it has been calculated that, if it were possible to release it from its frozen state, it could supply all of Canada's rivers for about 13,000 years, or all the rivers in the world for over 800 years. So far as the hydrologic cycle is concerned, this vast quantity of water is of very little importance, because it does not melt, or if it does, new ice is continually being added to replace what has melted. It is fortunate that the volume of ice in the ice caps remains constant, because any extensive melting of the ice caps would cause a rise in level in the world's seas which could have disastrous effects in coastal areas. The importance of the polar ice masses lies in the fact that, because they exert an influence on weather patterns, they indirectly affect the hydrologic cycle, even though they have no part in that cycle. There is, however, a considerable flow of ice to the sea as icebergs, representing a part of the hydrologic cycle that by-passes the liquid, streamflow phase.

Alpine glaciers, unlike the polar ice masses, exert a direct influence on the hydrologic cycle. Many glaciers can be compared in their effect to lakes or groundwater reservoirs in the sense that they provide storage. Water released by melting contributes to the flow in the rivers into which they drain. Water from melting glaciers frequently sustains streamflow throughout dry seasons where flow would otherwise cease. As in the case of lakes or other reservoirs, the importance of glaciers lies not so much in the actual quantity of



Snow, which is ice in another form, can store water in varying amounts for varying periods of time. Water from snowmelt is a major factor in the flow of most of Canada's rivers.

water contained in them as in the fact that, because glaciers can store water, they help to provide more uniform streamflow.

Snow, which is another form of ice, can store water for varying periods of time and in varying amounts. Consider, for example, the effect that snowfall in Canada has on the movement of water through the hydrologic cycle. Much of the total annual precipitation in Canada may occur in the form of snow. The percentage varies, of course, in different parts of the country. The north country receives half of its total annual precipitation in the form of snow, whereas on the prairies, snow represents 25 per cent and on both coasts and in southern Ontario as little as 10 per cent or less. Precipitation stored during the winter months in the form of snow exerts a very marked effect on the distribution of streamflow throughout the year. Instead of immediately infiltrating the soil or running off into stream channels as rainfall does, this water is stored for periods of as long as several months. When melting does occur, the water is then released to proceed through the usual phases of the hydrologic cycle.

Close to 50 per cent of Canada's streamflow occurs during a three-month period in spring and early summer, often resulting in flood conditions caused by the relatively sudden release of stored water when the snow melts. Above-average rainfall in spring and early summer is responsible for part of this concentrated runoff, but snowmelt is a major factor in the flow of practically all of Canada's rivers, as it is in most rivers in northern regions of the world.



Canada's lakes, probably more numerous than those of any other country in the world, have not been counted, much less measured.



Canada's Water

In terms of fresh surface water, Canada is one of the world's most fortunate countries. There are probably more lakes here than in any other country in the world, so many that they have not even been counted, much less measured. Estimates, however, have placed Canada's total lake area at 292,000 square miles. Since the country's total area is 3,852,000 square miles, this means that about 7.6 per cent of Canada is covered by fresh water. Most of Canada's lakes have not yet been surveyed but, including Canada's share of the Great Lakes, they contain as much as one seventh of the world's fresh, liquid, surface water.

Streamflow is the true measure of water supply

Not all the stored water in Canada's lakes is available for use. It would be unrealistic to suggest, for instance, that the entire 5,500 cubic miles of water in the Great Lakes, of which an estimated 1,800 cubic miles is in Canada, could be removed and used. The water is very valuable where it is, as storage which can be drawn upon in time of drought to be replaced in time of plenty. But the true measure of a country's water supply is in its streamflow rather than in its storage capacity.

Not all of Canada's rivers have been gauged but, based on actual measurements where these are available, supplemented by estimates for ungauged areas, it has been estimated that the combined average flow of all Canada's rivers is

about 3.5 million cubic feet per second.

This means that each year, on the average, Canada's rivers carry about 750 cubic miles of water to the oceans, almost 9 per cent of the total flow of all the rivers of the world. Set against a population which is less than one per cent of the world's population, Canada's endowment of fresh water is generous indeed.

Even though the flow is not uniformly distributed throughout the country, nor during the year (a

FLOW OF CANADA'S RIVERS

| River | Drainage Area (Square Miles) | Mean Flow (cfs) |
|----------------------|---------------------------------|--------------------|
| St. Lawrence | 503,000 | 540,000 |
| Mackenzie | 700,000 | 300,000 |
| Fraser | 90,000 | 100,000 |
| Columbia* | 40,000 | 80,000 |
| Nelson | 414,000 | 75,000 |
| Yukon* | 130,000 | 75,000 |
| Churchill (Labrador) | 30,000 | 60,000 |
| Skeena | 21,000 | 40,000 |
| Saint John | 22,000 | 30,000 |

*At International Boundary.





Canada's great rivers were the transportation routes used by explorer and fur trader in opening up the new land. Here, twentieth-century **voyageurs** re-trace the old routes followed by their predecessors almost two centuries ago.

large portion of the annual supply for example, is frozen for several months during the winter, to be released only when Spring arrives), the 750 cubic miles of water is available every year and is constantly replenished by the continual operation of the hydrologic cycle.

The table on page 25 lists the flows of some of Canada's larger rivers.

Canada's history has been moulded by the influence of great rivers

The country's first industry, the fur trade, depended upon the ready access provided by the St. Lawrence River, the Great Lakes and their

tributary streams and the many other great waterways which provided transportation to the interior.

The early settlement of the country depended on this same ready means of access. The plentiful water supplies of the flat, fertile plains of southern Ontario and Quebec, the river-borne transportation of lumber and later the power of water-driven turbines, all were vital factors in the building of a Canadian nation.

An adequate supply of fresh water is vital to modern Canada

Today, more than ever, water is the key to Canada's development, supplying the renewable

energy required in industrial growth, providing access to raw materials and playing a vital part in the processing of these materials.

Domestic and municipal supplies. Canada's earliest settlers, who had to carry or pump their household water supplies by hand, probably got by on five gallons or less per day for each person. Today each member of the average Canadian family uses from 20 to 70 gallons or more each day. Bathing, washing clothes and dishes, disposing of wastes, watering lawns and washing cars require considerable quantities of water and any curtailment of the supply arouses surprise and resentment. Fortunately, in Canada, shortages have usually been local and temporary. Most Canadians have not had to worry seriously about water shortages.

Despite its variety of uses, water is probably the least expensive material used in the household. Compare the price of oil for heating (20 cents per gallon) or gasoline for the automobile (50 cents per gallon) with the cost of water piped to the house (about one thirtieth of a cent per gallon in Ottawa). At a cost of 34 cents per thousand gallons, water costs about 7 cents a ton, delivered. No other material costs so little.

Commonplace, convenient, low in cost — it is hardly surprising that little thought is given by the average Canadian to this most necessary commodity.

Twenty gallons to take a bath or do the laundry, ten gallons to wash dishes, five or six gallons to

Canadians use between 20 and 70 gallons of water per person each day.





flush a toilet—all this water is used without much thought in the average household, which uses some 50 gallons a day per person. Industries located within cities also use a very large amount of water, much of which comes from municipal supplies.

The city of Ottawa in 1965 used 100 gallons a day per person. Winnipeg used 80 gallons per person, Vancouver and Montreal about 120 gallons and Toronto about 175 gallons per person per day. Industrial use accounts for most of the difference between the average of 50 gallons a day per person and the city's total consumption. Per capita use for domestic purposes probably does not vary appreciably from city to city.

Industry. Industry has an enormous thirst for water. The largest quantity is used for cooling purposes, but considerable quantities are also used directly in many manufacturing processes; another important use is in plant sanitation. Frequently, figures are published to indicate how much water is used in various industries — figures like 10 gallons of water to refine a gallon of gasoline, 18 barrels of water to refine a barrel of oil, 250 tons of water to produce a ton of sulphate wood pulp, 100 gallons of water to produce a gallon of alcohol. These figures are interesting as a general indication of the need for water, but they may be misleading. Far too often they reflect the fact that water is easily available, inexpensive, and therefore often used inefficiently.

Water is an essential element in all industrial operations.



Take, for example, the amount of water required in the production of steel. The usual, or average, amount of water used to produce a ton of steel is about 60,000 gallons; yet there is a steel mill in California which, by cooling and recycling its water uses only about 1,400 gallons per ton of steel produced. A wide variation like this is by no means unusual. When water becomes scarce, and therefore valuable, it can be and is used much more efficiently than if it is plentiful and cheap.

The fact remains, however, that water is an essential material in all industrial operations and increasing industrialization inevitably leads to greater use of water.

It is impossible at the present time to say exactly how much water is used by Canadian industry. Some industrial plants purchase water from their municipality. Others find it more convenient, or more economical, to develop their own water supplies by drilling wells, or by building their plants beside a lake or a river.

Many industrial uses are non-consumptive in nature — that is, the water is returned to a stream channel after it has been used. The returned water, however, is often polluted, either by the addition of undesirable material or by heating during use. Pollution of this kind is a constantly increasing problem wherever industry is concentrated in Canada, particularly on some of the Great Lakes, on the St. Lawrence River and on some rivers in British Columbia.

Since the turn of the century, water power has been the driving force behind Canada's industrial development.

Hydro-electric power development. Electrical energy has been called the master tool of mankind. In Canada, it is the economy's mainspring — the efficient servant of modern life. To a remarkable degree, it is true to say that the Canadian economy is a hydro-electric economy. Canadian industrial development, since the turn of the century, has depended upon water power as its principal source of energy and, despite the current emphasis on thermally-generated power, water power is still by far the leader.

Of the 158,000 million kilowatt hours of electrical energy generated in Canada in 1966, 130,000 million kilowatt-hours, or about 82 per cent, was generated in hydro-electric plants. Industry used over half of the total energy, commercial operations and street lighting about 15 per cent, and residential and farm almost a quarter of the total.

Every year, new generating capacity is added to help satisfy modern Canada's rapidly increasing demands. In recent years, there has been a marked trend to the installation of thermal plants, because in many parts of Canada, most of the hydro-electric sites within economic transmission distance of the population and industrial centres have been developed. Planners, therefore, have had to turn to other sources of electric energy. Canada still has a vast undeveloped hydro power potential which, if developed, would more than treble the 22.7 million kilowatts of hydro capacity installed at the beginning of 1967. Moreover,



recent advances in extra-high-voltage transmission techniques are providing a renewed impetus to the development of hydro power sites previously considered too remote. Already, work has begun on the development of the power potential of the Nelson River in Manitoba, the Churchill River in Labrador, and the Peace and Columbia Rivers in British Columbia.

Transportation. Water provides the most economic means of transportation for the bulky raw materials of Canada's vital export trade — wheat, pulp and paper, lumber and minerals on their way to the world's markets. The idea that inland transport by water was becoming obsolete has been contradicted by the continuing growth in the volume of water-borne goods not only in Canada but in the United States and Europe.

Annual freight traffic through Canadian canals and canalized rivers in the ten-year period from 1956

to 1965 increased from 40 million tons to 99 million tons, an increase of 150 per cent.

The \$470 million St. Lawrence Seaway, completed in 1959 (Canada's share of the cost was \$330 million) is an indication of faith in the future of water-borne transportation. In 1965, nearly 25 million tons of cargo moved up the Seaway, and over 35 million tons moved down.


On the Mackenzie River, the freight carried by the Northern Transportation Company (the major carrier on that river) in 1954 was 91,000 tons. In 1964 this had risen to 128,000 tons, an increase of 40 per cent.

Much of Canada's wealth depends on the forest industry and, for both the raw material and the finished products, rivers and coastal waterways have long been an important means of transportation and a key factor in the industry's economy.

Canada's waterways provide a re-made, economical means of transport — timber to the mills — wheat, pulp, paper, lumber and minerals on the stage of their journey to the market the world.





An aerial photograph showing a vast, flat landscape. In the foreground, there are large, rectangular fields, some of which appear to be irrigated, with distinct patterns of water and land. A small cluster of buildings, including a prominent white house with a red roof, is situated in the middle ground. The background shows a flat horizon under a clear sky.

Irrigation serves only one million of Canada's approximately sixty-five million acres of crop-producing land. The rest depends upon natural water supply from rainfall and snowmelt.

For large, bulky cargoes, transport by water is unlikely to be displaced as the most economical method and, far from becoming obsolete, water-borne transportation will likely continue its steady increase.

Agriculture. Most of Canada's agriculture depends on the direct natural supply of water to the land by snowmelt and rainfall. Of the approximately 62 million acres of land devoted to crops each year, an estimated 1,000,000 acres is irrigated — less than two out of every hundred acres of crop-producing land. Practically all the irrigated land is in Alberta, British Columbia, and Saskatchewan.

In Alberta, over 600,000 acres of the 15.6 million acres of land devoted to crops each year is irrigated (four per cent). British Columbia, with a much smaller area of land devoted to crops — about 800,000 acres — has over 200,000 irrigated acres (25 per cent).

Irrigation projects continue to be developed in the Canadian west. The South Saskatchewan River project, for example, will permit the irrigation of 500,000 acres in Saskatchewan; the Waterton River diversion, completed in 1964, has made irrigation water available to an additional 200,000 acres in Alberta.

In humid areas, where irrigation is not generally

required, methods of agriculture can have a substantial effect on streamflow. Careless farming methods can speed the runoff of rainfall and result in erosion of soil. Besides the loss of precious soil, this can have two effects on the streams which receive the runoff — it can increase the danger of flooding downstream, and it can cause streams to become turbid because of the eroded material being carried. Farmers are recognizing more and more the value to themselves and to others of proper agricultural practices which will conserve precipitation for crop use, prevent the loss of soil, and preserve the quality of the streams which drain the land.

Fisheries. In 1867, the year that Canada became a nation, some 3.5 million pounds of fish were taken from fresh water sources, primarily the Great Lakes-St. Lawrence River system. Since 1867, fresh-water fisheries have continually expanded to the extent that, by 1964, the annual catch had increased to 105 million pounds, worth \$18.3 million. A little less than half of this catch was taken from the Great-Lakes-St. Lawrence system.

Although this value is less than one-tenth the value of Canada's coastal fisheries, it should be remembered that the value of rivers lies not only in their yield of fresh-water fish, but also in the fact that they provide the spawning grounds for commercially profitable anadromous ocean fish.



The interests of commercial and sport fishing are an important consideration in designing water-use projects.

Besides the commercial fresh-water fisheries, there are thousands of sport fishermen who each year cast their lures into lakes and rivers in all parts of the country.

To an increasing extent, commercial and sport fishing are receiving important consideration in the preliminary design of water-use projects affecting fisheries. In some cases, this consideration has not only dictated the nature of the project but also has influenced the choice of location.

Fish require a pollution-free environment, and the increasingly-polluted condition of many lakes and streams has had a serious effect on both the quantity and type of fish available for sport or commerce.

Recreation. In 1941, little more than 50 per cent of Canada's population lived in towns and cities. In the 1960's, by contrast, town and city populations make up about 70 per cent of the total. Over 40 per cent of Canada's people, in fact, live in the thirteen cities with populations over 100,000.

This trend toward living in large urban centres has been accompanied by a desire to return occasionally to non-urban surroundings as an escape from the pressures of modern city life. The annual exodus from the cities during the summer months stems directly from the increase in leisure time enjoyed by most Canadians and the fact that



Canadians, living increasingly urbanized lives, look more and more to river and lake for recreation.

many more people now own cars (car ownership increased from one for every eight persons in 1949 to one for every four in 1963).

Much of the recreation sought by holidaying Canadians is water-oriented. Swimming, fishing, boating, water-skiing, all increasingly popular, require clean water. But many rivers and lakes close to urban centres are polluted to such an extent that they are useless for recreational purposes. This increases the demand on those which are suitable, and creates also a demand for new recreational lakes. The demand is such that many large reservoirs have been built with recreation as one of their primary purposes. The South Saskatchewan River project is one example.

Several of the flood control and conservation dams built recently in southern Ontario are designed so that their reservoirs can also be used for recreational purposes. Five reservoirs to be built in the Metropolitan Toronto region have recreation as their only purpose.

Recreational requirements are no longer overlooked in the development of water-use projects. The demands of recreational interests have in some cases been strong enough to affect decisions involving the location of hydro power projects. How an existing project is operated is frequently influenced by the effect it will have on recreation.



Pleasure boating on natural and artificial waterways has shown a phenomenal increase in the past few years. Thousands of pleasure craft travel the rivers of Canada every year, retracing the old voyageur routes that once carried the commerce of a young nation. The Rideau Canal from Ottawa to Kingston, built in 1830 for national defence, has for many years been a popular waterway for pleasure craft travelling between the Ottawa and the St. Lawrence Rivers. The Trent Canal System is another mecca for pleasure boat operations.

A growing awareness of the recreational value of clean water to the country, to say nothing of the tourist dollars which water-oriented recreation can attract, will undoubtedly give rise to many programs for the restoration of natural waterways which have become damaged or destroyed through indifference.

Waste disposal. Usually last to be mentioned, but far from least in importance, is the vital service which water renders in diluting and carrying away the wastes of a modern society. Unfortunately, this use leads easily to abuse, as demonstrated by the condition of most of the rivers serving populated areas.

Because of the apparent abundance of water in this country there has been a tendency to ignore or forget the fact that there is a limit to the amount of waste material which can be absorbed by any watercourse. The rapid growth of large population centres and the expansion of industry in certain areas of Canada, have produced un-



pleasant evidence of what uncontrolled pollution can do to a river, and this is beginning to correct the complacent attitude of Canadians to water.

There can be no suggestion, of course, that Canada's rivers should not be used to transport waste. Water is an efficient and an economical carrier of undesirable materials. To a certain extent it can, by natural processes, dispose of those materials, but there is a limit, both in quantity and type of waste, beyond which the river is incapable of recovery. The prohibition of all waste products from streams is as impractical and undesirable as the excessive use of streams for this purpose.

The goal of wise water management is the attainment of an acceptable, economic balance which takes into account all the many and varied services which a stream is called upon to render.

Water renders a vital service in diluting and carrying away the wastes of a modern society. If it is not assisted in its diluting function by waste treatment installations, it may be poisoned beyond hope of recovery.

The goal of wise water management is the attainment of an acceptable, economic balance which takes into account the many and varied services which a stream is called upon to render.



HOW MUCH WATER?

Animal

A human can survive on about three quarts of water a day. A little less than half of this is usually taken in or produced by the oxidation of food. The rest must be consumed as fluid. The necessary amount varies with the weight and health of the person, with the level of activity, and with the climate. Without water, humans could live for a few days if inactive, but with any activity, death may result from a single day's lack of water. Other animals vary greatly in their consumption of water, depending on their weight, the temperature, the type of food eaten, and other factors. The following figures give some idea of the quantities of water consumed by adult animals:

For sheep, the consumption varies from almost no water on good pasture to 17 pounds per day on dry range.

Pigs drink from 5 to 30 pounds per day depending on their weight (a 100-pound pig, for instance, drinks about 15 pounds per day). Lactating or pregnant sows may double this consumption.

Chickens will drink from 25 to 60 pounds a day per hundred birds.

Depending on their size and feed, and on the temperature of the surrounding air, cattle will drink from 30 to 70 pounds a day; milk-producing cows double this (a Holstein cow producing 80 pounds of milk a day can

drink as much as 200 pounds of water a day).

The camel, the "ship of the desert", can go for several weeks with no water beyond what is contained in its feed. Even on dry feed, it can still go for long periods without drinking. Under these conditions it loses considerable weight, but even a 25 per cent loss of weight produces no ill effects. When water becomes available, enough is drunk to restore the normal weight — one camel, after several weeks without water, was observed to drink 270 pounds in a ten-minute period.

Vegetable

In plants, water represents from 80 to 90 per cent of the total weight. For every pound of plant produced, several hundred pounds of water must be made available in the soil to be absorbed by the root system. Most of this water passes through the plant and is returned to the atmosphere by evaporation from the leaves (a process known as transpiration). The total amount of water used by various plants in their growth cycle varies to a great extent with the climate. It is difficult, therefore, to state exactly how much water a particular plant may require.

A few examples may illustrate this variation:

Forage crops, including pasture, require from 1 to 6 feet of water during their growth period.

Potatoes and sugar beets require from 1.5 to 3.5 feet.

Cereal grains, from 1 to 2.5 feet.

Fruits, from 1.5 to 3.5 feet.

Garden vegetables, from 1 to 4 feet.

Where the total precipitation during the growing season is not sufficient to provide these amounts, or where the precipitation occurs at an unsuitable time, the crop cannot be grown, unless supplementary water is supplied by irrigation.

Industrial

The water requirements of animals and plants are related to physiological processes and are dependent on natural variations, but the requirements in manufacturing are to a large extent dependent on the availability and the cost of the water. Water is a very efficient and economical agent for the removal of heat, and most of the water required by industry is used for cooling purposes. Very little of the water used for cooling is actually consumed; almost all of it is returned to the source, the only effect being an increase in the water temperature.

A small amount of the water used by industry is involved in waste disposal. Again, most of this water is returned after use, although its quality may be impaired. In all, considerably more than 90 per cent of all the water used by industry is returned to streams and is available to

be used again. The extent to which the returned water can be re-used for other purposes depends upon its condition. It may be, and often is, either too warm or too polluted for satisfactory re-use without some form of treatment.

Because the amount of water used depends on the availability, and thus the cost, it is almost impossible to give a meaningful figure for the water requirements of various industries. Some general idea may be derived from the following:

To make a pound of aluminum takes from less than 2 to more than 35 gallons of water.

To make a ton of synthetic rubber takes anywhere from 20,000 to 40,000 gallons.

To process 100 pounds of sugar from sugar beets may take less than 100 or over 3,000 gallons.

For a ton of steel, from less than 2,000 to as much as 70,000 gallons of water may be used.

It would seem to be the better part of good sense to say that, because one industrial plant can use a minimum amount of water by recirculating and cooling, all similar plants should do the same thing. This may not always be desirable, however. Recirculating the water may well increase consumption because of evaporation. Depending on the situation downstream, it may be more efficient to withdraw huge quantities and return a larger percentage of this withdrawal for downstream use.





Water Problems in Canada

Every year, about eight thousand billion tons of water in the form of rain and snow falls on Canada. Much of it is evaporated, but a large amount drains back to the ocean as surface run-off, forming rivers and lakes along its route. This surface water, ceaselessly moving, is the dominant feature of the Canadian environment.

The total flow of Canada's rivers averages about 3.5 million cubic feet per second, or some 94,000 gallons per person per day. The United States has an estimated river flow equivalent to 5,000 gallons per person per day. Egypt has about 2,000 and Israel about 500 gallons per person per day.

Statistics like these tend to lead Canadians to consider that the nation's fresh water supplies are virtually limitless and that whatever problems exist are of little consequence. As a result, there is a very real danger that the necessity of conserving and protecting Canada's water resources may be treated with indifference.

What then are these problems and why should Canadians be concerned about them?

The major problems in water resource management are floods, shortages and pollution. The first two are concerned with quantity — the third with quality.

Floods are the result of too much water in one place

A flood occurs when a lake or a river channel is unable to contain the amount of water it receives. The result is an inundation of what is usually dry land.

Floods can sometimes be caused by the failure of a dam or other hydraulic structure, but floods of this type can be eliminated by proper engineering and construction methods. Natural floods, however, are an integral and often important part of the human environment. They are not always a menace. In the early days of settlement in eastern Canada, for instance, the periodic swelling of the rivers and streams played a large part in the economic life of the settlers. In years when there was no flood, transportation of lumber was



hindered. In the early nineteenth century in Ontario, floods were considered to have another advantage—they were thought to enrich the meadows with silt. Even in this century in the Assiniboine River valley in Manitoba, the value of land subject to floods was greater for the same reason.

Are floods today greater and more frequent than they were a century ago?

It is a commonly-held belief that floods are more frequent or severe today than they were in earlier times. The basis of this belief is the theory that floods are caused by denuded watersheds—that the removal of forests has increased the magnitude of large floods. Long periods of record on European rivers (800 years on the Danube, 350 years on the Seine), however, show that in spite of deforestation there has been no increase in either the magnitude or the frequency of floods in these regions.

Forest or other vegetative cover certainly does slow down the rate at which surface water flows to the main channels and hence spreads the runoff over a longer period, at the same time reducing the peak flow. This effect is significant, however, only in the case of small streams and small floods.

Great floods overcome all the retarding effects of

vegetation, and the nature of the land surface becomes of very little importance as a factor in slowing runoff. There is nothing to indicate that the frequency or magnitude of large floods in Canada is any greater today than when the country was young.

Floods today are usually much more damaging

It is undoubtedly true that floods, when they do occur, cause more damage now than they did, say a century ago, but this is because there is more property to damage now than there was when the country was first settled. Take, for example, the 1826 flood on the Red River in Manitoba, the greatest flood known to have occurred on the Red River. It was disastrous to the few settlers who lived in its path, but the actual property damage in dollars was relatively small.

Were such a flood to have occurred up to 1967 (and there is no reason why it could not) property damage could well have approached the billion dollar mark. This is because the entire city of Winnipeg and most of its suburbs would have been inundated (from the autumn of 1967 the threat of such an inundation has been removed by the construction of the Red River Floodway, a \$63 million by-pass channel which will carry flood waters safely around the city).

Practically every city in Canada is on a river, and the most desirable land is usually the land closest to the water. Access to transportation, convenient water supply, relatively level land for building, fertile land for crops, a pleasant view — all these advantages are to be found on land which fronts the river and because of this, the river banks are often completely occupied by business establishments, industries or residences. But there is a price to be paid for riverside property which often far exceeds the actual purchase price of the land. This is the price that is demanded from time to time by the river itself, a price that must be paid in the form of flood damages, or increasingly nowadays in the form of flood protection works.

Preventing flood damage

There are only two basic ways to prevent damage from floods. One is to prohibit use of the flood plain (the name given to low-lying land used as a natural extension to the river channel during periods of high flow). This may in many instances entail removing vulnerable property, people, livestock and buildings from the flood plain. The other is to prevent the water from overflowing the banks of the river.

Rarely is the use of flood plain land so nicely adjusted as it was in the ancient valley of the River

Nile, where each year the people merely moved out of the flood plain when it was inundated and moved back again to till and crop the land after the flood had receded. Such an arrangement depends on being able to move everything damageable from the flood area; it also depends on an accurate forecast of the time and height of the flood. This is the most obvious method of flood control.

Recently, a number of municipalities in Ontario have passed by-laws prohibiting the construction of residential and commercial buildings on designated flood plain land. Such land is recognized as belonging to the river. It is used only at times when it is not occupied by the river, or for purposes which will not be affected unduly by flooding. Any structures which must be located in the flood plain are made flood-proof.

Where the flood plain is already occupied, flood waters must be controlled

Where the flood plain land is occupied by valuable and permanent structures whose removal would be economically impractical, as is the case in many communities, flood protection must be provided to avoid or reduce damage. There are four methods of doing this — dyking, channel improvement, diversion, and flood storage.





To be satisfactory as a permanent means of flood protection, dykes must be built high enough to protect against the highest flood of which the river is capable.

As a means of local or temporary protection, dykes built of earth, masonry, or concrete are frequently used. In emergencies, dykes are often constructed of sandbags.

Dyking. Local protection by dykes — barriers of earth, masonry, or concrete — to prevent flooding is feasible on nearly every stream, and they are often used as temporary protection. As permanent measures, however, dykes are not usually satisfactory because, unless they are built high enough to protect against the highest flood of which the river is capable, there is the ever-present danger of overtopping, with the prospect of far greater damage than if the dykes had never existed. The maintenance of dykes is a problem, too. Rivers object to being confined, and are continually tending to erode the dykes. Expensive protective facing or constant maintenance is required to prevent local failures. Any breach in a dyke, of course, renders the entire system useless. As complementary measures to other forms of protection, however, dykes can be very use-





Improving a river channel may lessen flooding by increasing its carrying capacity.

The Red River Floodway is one of the largest single-purpose flood control projects in the world.



ful. There are examples of permanent dykes for flood protection along the Fraser River in British Columbia and the Red River in Winnipeg.

Channel improvement. On some rivers, deepening, widening, or straightening the river channel may lessen flooding by increasing the carrying capacity of the channel. The benefits, however, are confined to the improved reach and a short distance upstream; downstream, flooding may be increased by bringing the flood waters to the unimproved section in quantities greater than would be the case under normal conditions. Channel improvement has been carried out on numerous rivers in Canada. Examples are the Pembina River in Alberta, and the Thames and Humber Rivers in southern Ontario.

Diversion. In some cases, flood damage can be prevented by diverting the flood waters from their normal channel into an artificial channel or into another natural channel, thereby removing the flood water from the area to be protected. Obviously the diverted water cannot be allowed to create a new flood hazard in the area to which it is diverted. The most notable flood diversion project in Canada — it is in fact one of the largest single-purpose flood control projects in the world — is the Red River Floodway, designed to protect Metropolitan Winnipeg from recurring disastrous floods by carrying flood waters from the Red

*"And gather the floods as in a cup,
And pour them again at a city's drouth."*

"The Sons of Martha" — Rudyard Kipling.

River safely around the built-up area and emptying them back into the natural channel several miles below the city.

Storage. The benefits to be derived from retaining flood water temporarily in reservoirs are generally greater than can be obtained through other methods of flood control. Flood water storage may be in small inexpensive farm ponds or it may be in huge reservoirs costing millions of dollars; the principle is the same. During the period of high flow, excess water is stored above the protected area in a reservoir until such time as water levels in the downstream reaches of the river have dropped to the point where water may be safely released. Examples of flood control reservoirs in Ontario are those created by the Fanshawe and Wildwood Dams on the Thames River, the Conestogo Dam on the Grand River, and the Claireville Dam on the Humber River. One of the aspects of this method of flood control that makes it so attractive is the fact that, in addition to being extremely effective for its primary purpose, stored water can later be used to augment river flows downstream for such purposes as recreation, navigation and hydro-electric power generation.





Storing flood water in reservoirs is one of the most effective methods of flood control.

A shortage of water occurs when the demand becomes greater than the available supply

It is important to realize that two factors — demand and supply — are involved in the problem of water shortage and that these two factors indicate two areas of solution, namely, increasing the supply of water or reducing the demand for it.

The danger of an overall shortage of water in Canada is remote. Canada's population and industrial development could multiply many times before an overall shortage of water would even become imminent. This is not to say that there are no local shortages from time to time in various parts of the country, but for the most part these shortages are caused by a lack of local facilities for the storage, purification and distribution of water. Regional shortages of this kind will continue to occur particularly in areas where rapid and unplanned expansion and industrialization take place. With sensible water management policies, however, there is no reason why such shortages need be more than temporary local problems.

The part of Canada most susceptible to water shortages is the western prairie region. Prairie precipitation is low and much of the precipitation which does occur is quickly evaporated and returned to the atmosphere. Fortunately, a major river system — the Saskatchewan — traverses the dry agricultural portion of the prairies. A partial

answer to the problem of aridity in the prairie region lies in the development of the Saskatchewan River system. Other potential sources for the future are the as yet unmeasured fresh groundwater aquifers. The amount of water that can be used, without exceeding the average recharge, is known only for some of the shallower aquifers because they are the only ones which have been fully explored. A further potential that is not so readily used is the saline groundwater from deep aquifers.

In the early 1960's, up to 1965, eastern Canada experienced a series of years of low rainfall, which caused considerable distress to large segments of the economy. As groundwater levels receded, many wells ran dry. Most spectacular of all, the levels of the Great Lakes dropped to record low points causing difficulties with water supply intakes, transportation problems as shallow navigation channels forced the reduction of loads in some of the ships using the Lakes, and the abandonment of docks at some locations. Again, this was a temporary situation. In the midst of the drought, many people forgot that in the early 1950's the same areas suffered from an over-supply of water marked by flooding which caused considerable damage. The low periods will inevitably pass, water supply and levels will return to normal and at times will even move beyond normal to a high water level condition. By 1967, in fact, levels in all the lakes had risen to about normal.



Conditions like these, typical of parts of the prairie region in the 1930's, were caused by protracted drought.

Whether a shortage is local, widespread, temporary or chronic, the cure is either to increase the supply or reduce the demand

The supply of water in any particular area can be increased by importing from an area where it is not being used. In Canada, there are many rivers, particularly those flowing northward to the Arctic, which are at present virtually unused for any purpose. The flow in these rivers represents a vast source of supply and while there may be economic reasons there is no physical reason why water from these rivers cannot be redirected southward to other parts of Canada where the local supply is either inadequate or may become so in the not-too-distant future. Some rivers have already been diverted to a limited extent. In Ontario, for instance, the Long Lac and Ogoki diversions carry water from Hudson Bay tributaries into Lake Superior (for hydro-electric purposes).

With modern engineering techniques, river diversions present few problems and the only barriers are usually economic ones. But when increasing demands make water more valuable, then the economics of diversion become more attractive.

The alternative to an increased supply is a reduced demand. This can be achieved by using the water already available in a more efficient manner. Very often the fact that water is in short

supply leads automatically to better use, as people are forced to achieve the same results with smaller quantities.

Water can be re-used again and again, but each use generally reduces its quality

One of the most important properties of water is its chemical stability. It can change to its different forms — vapor, liquid, solid; it can be mixed with other materials — salts, suspended solids, pollutants; but the water itself is chemically unchanged and can be re-used again and again.

The re-use of water is by no means an innovation. On any river where there are several industries and municipalities, every user except one is downstream from another, and is therefore receiving water which has been used before. And there is no reason why this cannot be done, safely and economically. Nor is there any limit to the number of times the same water can be used, provided it is returned to the stream undiminished in quantity.

Most uses of course, lessen to some extent the quality of the water. This is compensated for by the natural tendency of water in a stream to restore itself to its original quality. As uses multiply, however, the stream may need assistance in the process of recovery. If the assistance is not given and the water becomes more and more



DESALINATION

Desalination, the process of removing salt from sea water or brackish water to produce fresh water, is attracting increasing attention in water-short areas of the world. The process is by no means a new one — Aristotle, in the fourth century B.C., taught that condensing the vapour from sea water produced "sweet water". It is only recently, however, that purification of salt water on a large scale has shown any indications of economic feasibility.

The use of desalted water is practical only when the desalted water competes in price with natural fresh water or when the supply of natural fresh water is not adequate. The techniques and equipment used in desalination are improving all the time, with a consequent reduction in costs. On the other hand, increasing demands for limited supplies are boosting the price of natural fresh water. The combination of these two factors enhances the feasibility of desalted water as a substitute for or a complement to natural fresh water. Some parts of the world, in fact, have already come to the point where the population must depend, either partly or entirely, upon desalted water for existence.

Where in 1952, the cost of producing 1,000 gallons of desalted water was close to \$5.00, the cost is now between \$1.25 and \$1.80, or even less where the source is brackish water with a relatively low salt content. Commercial or demonstration installations with capacities up to a million gallons a day are now in operation, and plants with between 10 and 100 times this capacity, with costs less than 30 cents per thousand gallons are in sight.

Distillation, the oldest method of desalination, was the method first used during the early stages of the current development program, and in fact, most of the world's large desalination plants use variations of this principle.

Basically, distillation involves the evaporation of the salt water to form water vapour and the condensation of the water vapour to form fresh water. Developments in the distillation process of desalination have been directed chiefly towards sophistication of techniques and equipment.

Other processes employ semi-permeable membranes for the removal of the salt. Electrodialysis, at present the most important process of this type, has been used successfully to treat brackish waters, but cannot compete economically with distillation in the desalting of sea water. Reverse osmosis is another process which shows promise.

Separation of salt from water by freezing is another principle which is being employed in some demonstration plants.

Other methods are being studied at the laboratory level, but they do not appear to have any immediate practical significance.

Canada's interest in desalination springs, not from any overall shortage of water, but from the possibility that, in certain localized areas, desalination of sea water or brackish well water may prove economical. There is also the likelihood that, as re-use of waste water becomes an economic necessity (as may well be the case in areas of heavy use), desalination will be an important part of the purification process.

For most of Canada, however, the only form of water desalination likely to be encountered is that which is involved in the oldest system of all — nature's hydrologic cycle.

One of the problems of heavily-populated regions is a new form of water shortage — a shortage of clean water.

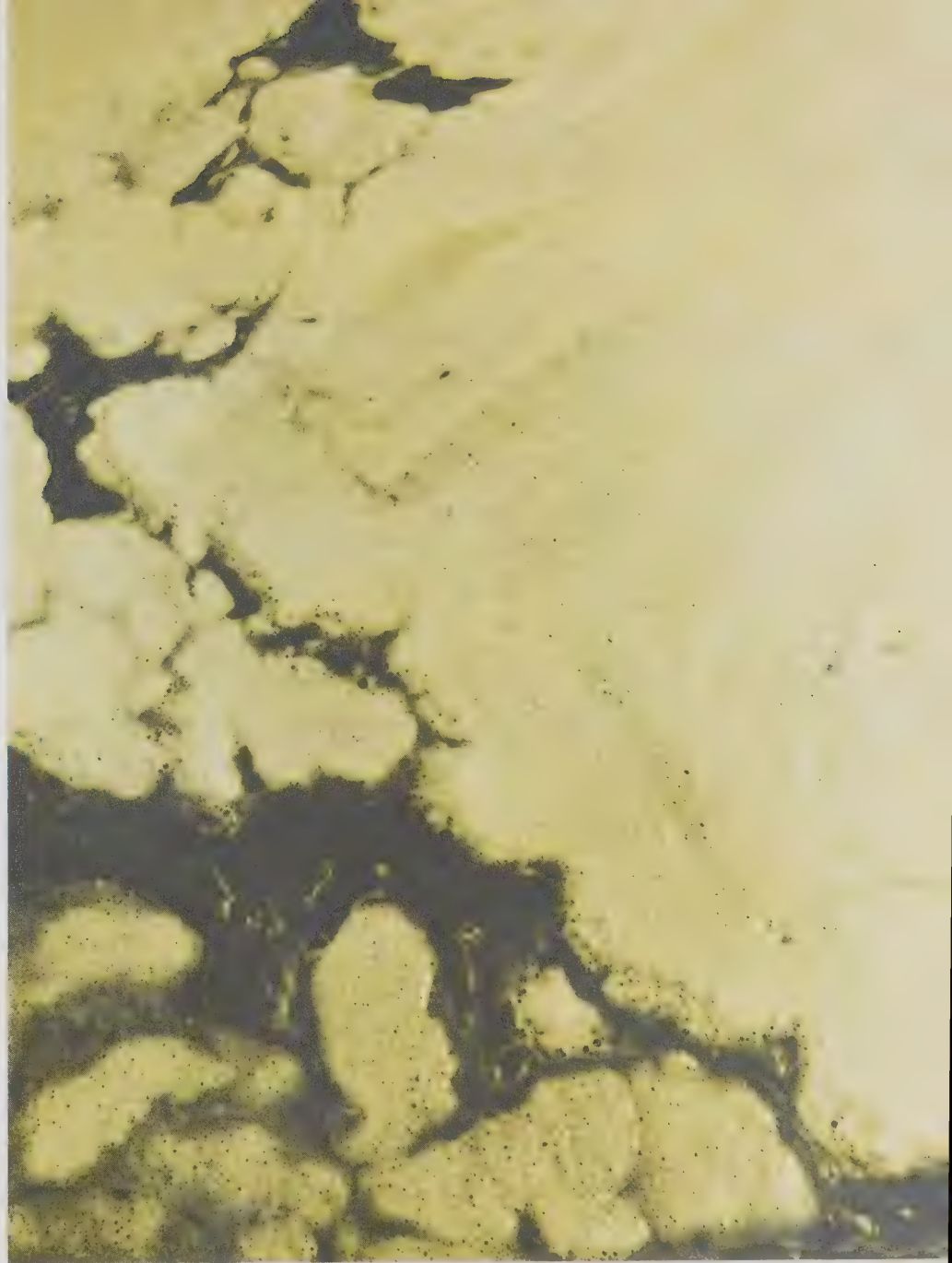
polluted, in the end it is nothing more than an open sewer, useless for any other purpose.

This is one of the major problems facing water users in heavily populated regions. It is a growing problem and it is creating a new form of water shortage — a shortage of clean water.

Man-made pollution is a modern society's most serious water problem

Statistics on pollution in Canadian waters are few. Pollution rarely becomes a matter of general concern until its effects are noticeably bad; when, for instance, fish or wildfowl are destroyed, water-borne epidemics are caused, or when the taste or odor of water used for drinking or cooking becomes offensive. The advent of detergents has caused problems. One problem is the stimulation of algae growth as a result of phosphate nutrients supplied by the "builders" or additive materials mixed with the detergent powder. Another is the appearance of foam in rivers and streams. The latter problem is mainly aesthetic, however, and has been largely eliminated by the new biodegradable detergents now being produced. The major pollution problem, however, still remains.

Water in its natural state is never absolutely pure. Raindrops form about a nucleus of minute particles and as they fall through the air, they gather





more impurities. In its downward passage to the ocean, even a wilderness stream, far from man's influence, continually acquires dissolved and solid material.

To these natural impurities, man adds his contribution of pollutants, and it is this human contribution which is responsible for some of the greatest problems in water use. Pollutants added by man's activities (besides the naturally accumulated materials and the sediment which results from improper land use) are of two general types — domestic wastes from sanitary sewage and wastes from industrial processes.

Sanitary sewage includes used water from bathtubs, sinks and toilets and washings from restaurants, laundries, hospitals and hotels. Municipal water purification systems, where they are used, provide an effective means of removing offensive or dangerous materials found in sanitary waste. But as serious as are the dangers from disease-causing organisms in sanitary waste, this problem of purification is a minor one compared to the problem posed by industrial wastes.

Industrial wastes are often unaffected by municipal sewage treatment systems

Most of the common pollutants in domestic sewage are easily handled by well-known and tested techniques — sedimentation, oxidation and chlorination. Industrial wastes, which include acids and other chemicals, oil, grease, animal and vegetable matter, present a much greater prob-

lem, both in volume and complexity. Special processing may be required for many of these materials. Ordinary municipal treatment plants often have no effect on them, and if they are discharged into municipal sewers, as is often the case, they may pass through the treatment plant and be returned unaltered to the rivers. The practice of discharging industrial wastes into municipal sewer systems complicates tremendously the problem of municipal waste treatment. Industrial wastes are sometimes discharged into water-courses through separate outlets, often without any form of corrective treatment whatever.

Waste products cannot be avoided and are bound to grow in volume with the growth in population and industry. At the same time, the demand for clean water increases. The conflict inherent in this situation is now confronting governments at all three levels with the urgency of taking co-ordinated action on a national scale, to carry out the research necessary for a thorough understanding of pollution, its effects and treatment, and the institution of a series of effective controls designed to restrict the indiscriminate dumping of pollutants into the nation's waterways.

To save money by postponing installation of treatment facilities is false economy

Treatment facilities are expensive, but the operating costs (at least for municipal treatment) are surprisingly low. In Canada, municipal sewage treatment, where it is provided, costs no more per family than the price of the daily newspaper.

Municipal sewage treatment in Canada costs no more per family than the price of the daily newspaper.



It may seem less expensive to dump sewage untreated into a river, but it is merely postponing the problem until its solution will cost many times more than a treatment plant had it been built at the outset.

It must be remembered that, as water becomes overloaded with waste, it loses its natural purifying function. Moreover, the condition may worsen to the point where, instead of resisting pollution, the balance is shifted and nature begins to work at increasing the pollution as it has in some parts of Lake Erie, due to the excessive growth and ultimate decay of large quantities of algae.

Lake Erie is showing signs of stress due to excessive pollution load

Thermal stratification prevents aeration of the bottom waters of temperate lakes during summer. Each spring, these waters have a high concentration of oxygen, but during summer the concentration gradually decreases as organic matter decays. Reaeration occurs each autumn when thermal stratification disappears. The earliest available observations in Lake Erie in 1929 showed that only about half of the oxygen in the central bottom water was used up by the end of summer. In 1968 almost all of the oxygen was used up before reaeration in mid-September. The increasing rate of oxygen depletion is the result of a process known as eutrophication. Plant

nutrients found in sewage and in some industrial wastes have enriched the water to the extent that the growth of aquatic vegetation, including algae, is stimulated. When the algae die and sink to the bottom, they provide food for micro-organisms which make use of dissolved oxygen. As the bottom oxygen is depleted, more plant nutrients are released from the bottom sediments into the water, stimulating plant growth even more. This cycle of plant growth and decay becomes self-supporting and carries on whether or not more nutrients are added. Lake Erie may already have reached this stage and if it has, even if all new nutrient material were cut off, the lake could remain eutrophic for many years to come.

Over three million persons in the United States and 150,000 in Canada take their water supplies from Lake Erie. The many industries along the shores of the lake take an even greater amount. The additional cost of treating the water before it can be used results at least in part from not adequately treating the wastes before they are discharged into the lake.

It is completely unrealistic to suggest that wastes should not be discharged into lakes or rivers. Waste disposal is and will continue to be a very important function of water. But there can be no justification for exploiting the waste disposal function of water indiscriminately, because to do so is to render this most valuable resource unfit for many of the other uses for which it may be required.

Over three million persons in the United States and 150,000 in Canada take their water supplies from Lake Erie, the most heavily polluted of all the Great Lakes.



Water Resource Development and Conservation

Water, as a resource, has certain characteristics which make it unique. The amount of water available varies continually but the supply is constantly renewed. Unlike the resources of coal or oil or gas buried underground or the resources of our forests, water cannot be conserved by non-use. Last year's water, flowing unused to the oceans, is forever lost to use, although each year a new supply and a new opportunity to use it becomes available.

Conflicting demands for water often complicate river development

Some of the uses of water require that it be withdrawn from its natural location; whether it be river, lake or well; for others, there is no such requirement. In some cases, the water withdrawn is returned but with its quality changed; in others, the water is not returned. For the purposes of transportation, hydro-electric power production and recreation, water may be used in the existing channel. For municipal, domestic, industrial, and agricultural purposes, however, water must be withdrawn from its source of supply. In municipal and domestic use, most of the water is not consumed, it is usually returned to a stream practically undiminished in quantity, but often changed in quality because of the wastes that have been added. In industry too, the water is generally returned only slightly reduced in quantity, al-

though the quality has usually been substantially reduced by pollutants, or in some cases by heating, itself a form of pollution which can be as deleterious as chemical or organic pollution.

On the other hand, most of the water required for irrigation is not returned to streams. While municipal and industrial uses consume only about 5 to 10 per cent of the water withdrawn from the supply, irrigation consumes more than half, perhaps more than 80 per cent. Some of the water withdrawn for irrigation is used in plant growth. Most of this is returned to the atmosphere by evaporation from the soil and by transpiration from the plants. The remainder percolates into the ground to become groundwater and may later reach a stream. The portion of the water which is returned to streams often contains salts in varying amounts, which lessen its quality.

When the same water has to be used for a variety of purposes, as is frequently the case, then the business of reconciling conflicting demands for limited supplies of water becomes an exceedingly complex one. In Canada, conflicting demands for water are a comparatively recent manifestation. There has usually been plenty of water for everyone, and even the thought of an incipient problem of this kind has seemed remote. In less fortunate countries, however, conflicts are as old as man himself. The very word "rival" comes from the Latin word for stream; rivals were originally per-





sons who lived on the same stream and competed for the use of that stream.

Conservation (wise use) is simple in concept but difficult in application

Conservation or "wise use" of water — a seemingly straightforward objective — is not always simple in application. Consider, for example, the case of a river which flows through a large tract of land which would be suitable for agricultural purposes if irrigation were possible. Downstream, there is a site on the river which would be suitable for a hydro-electric power plant. The choice for the developer is to withdraw water from the river to spread on the land to produce crops, or to leave it in the river to flow through the turbines of a power plant to produce energy. The obvious approach to a solution to the problem is to calculate the value of the extra crops which irrigation would produce and the value of the electric energy which the power plant would make available. By comparing the net dollar benefits, the choice appears simple. But there is more to it than that!

The developer must ask himself — is a dollar's worth of food production equivalent to a dollar's worth of energy? Here, there may be room for argument. But if the economic analysis is complete enough, and the indirect benefits in both cases are taken into consideration, the answer must be — yes, a direct comparison of the dollar values for the two projects is valid.

But then other considerations arise which complicate the problem. If water is withdrawn for irrigation, very little of it is returned to the river for use downstream. Perhaps a city lying below the irrigated area will be denied an adequate water supply for domestic and industrial purposes. On the other hand, if the water is used for power, it remains in the river to be available for use again, perhaps several times. After it has given up its energy in driving the turbines, it can be used downstream for irrigation, to supply a city or even to develop energy a second time.

It can be seen, therefore, that the only satisfactory approach is to consider *all* these factors, assign dollar values to downstream benefits *increased* or *foregone*, and then make a comparison of net benefits.

Integrated river basin development

This approach leads logically to the concept of integrated river basin development, in which the basin is considered as a unit and the river and all its tributaries studied in conjunction with all the other resources, human and otherwise, within the basin. On this broad basis, a comprehensive plan of development can be prepared, which will see the water used for appropriate purposes in appropriate locations, balancing energy production, agricultural, municipal, industrial, and other uses in the most practical and economic way possible.



It is difficult to assign dollar value to wildfowl habitat.

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Such a development plan may travel a considerable distance along the road to true conservation — or wise use. But even at this point, there are still other effects which cannot be ignored. A completely pragmatic approach can overlook values which, although they are difficult to assess, are nevertheless real.

Suppose, for example, that because water is withdrawn for irrigation, a marshy area downstream deprived of water, is wiped out and a feeding ground for wildfowl is destroyed; or a lake which forms a recreation area for a town is rendered unusable. Or suppose a reservoir which impounds water for power or irrigation floods out a wilderness area where wild animals abound.

It is not easy to assign dollar values to wildfowl habitat or recreation, to sport fishing or hunting, although attempts are often made. But because of their very nature, water uses which produce financial benefits cannot satisfactorily be compared with uses which have mainly aesthetic or other non-objective values.

The extent to which true conservation of the water in a river basin is achieved will always reflect the wisdom and foresight that have gone into the development of the master plan. True conservation will always rest on a fine balance between conflicting uses on the one hand and between aesthetic values and material needs on the other.

Administration of Water Resources in Canada

The division of legislative powers between the federal and provincial governments in the field of water resources is set out in Canada's Constitution — the British North America Act.

With the exception of water on lands within the provinces owned by the federal government (such as National Parks) and water in the northern territories, Canada's water resources belong to the provinces. Legislative authority over the use of water resources, however, is divided. Domestic and industrial water supply, pollution control, power development, irrigation, reclamation, recreation — all these fields are reserved to the provinces. Federal authority, on the other hand, extends to navigation, fisheries, interprovincial and international matters and to a number of other fields where the national interest is concerned.

Within this framework, statutes dealing with water management have been enacted both by the federal parliament and by provincial legislatures. Because of the size of the country, however, the approaches to water management are as diversified as the many physical, economic and social conditions by which they are influenced.

The different approaches are reflected in the provincial statutes and the agencies which administer them; while there are many similarities, each framework differs from all the rest. The

picture is further complicated by the fact that political boundaries seldom coincide with watersheds. The difficulties in administration which can arise where important rivers and lakes cross political boundaries are obvious.

No attempt is made here to describe the water administrations of the various provincial governments. In general, they are characterized by a large number of agencies administering numerous Acts and performing a variety of functions. Some provinces, in the interests of more effective water management have, in recent years, consolidated the agencies dealing with water into a single department or have in various ways co-ordinated the activities of these agencies.

FEDERAL GOVERNMENT INTEREST IN WATER

Nine federal departments and a number of Crown Corporations and Agencies have varying degrees of responsibility in the field of water . . .

| | |
|--|--|
| Department of Agriculture | Canadian Maritime Commission |
| Department of Energy, Mines and Resources | Central Mortgage and Housing Corporation |
| Department of External Affairs | Fisheries Research Board |
| Department of Fisheries | International Joint Commission |
| Department of Forestry and Rural Development | (Canadian Section) |
| Department of Indian Affairs and Northern Development | National Energy Board |
| Department of Public Works | National Harbours Board |
| Department of Transport | National Research Council |
| Department of National Health and Welfare | Northern Canada Power Commission |
| Atomic Energy Control Board | Northern Transportation Company Limited |
| Atlantic Development Board | St. Lawrence Seaway Authority |

The federal Department of Energy, Mines and Resources has been given the main responsibility for water policies and the co-ordination of activities at the federal level.



The Government of Canada recognizes a national responsibility to foster the development of Canada's water resources for the benefit of all Canadians.

The federal responsibility is administered, as at the provincial level, through a framework of agencies and statutes. There are nine federal departments and several Crown Corporations and agencies which have varying degrees of responsibility in the field of water. The Department of Energy, Mines and Resources has been given the main responsibility for water policies and the co-ordination of activities at the federal level.

The federal government, in addition to its direct responsibility in connection with navigation, fisheries and international waters and the direct control of water resources under its jurisdiction, has a general responsibility to foster the development of Canada's water resources for the benefit of all Canadians, both present and future. The federal government discharges its general responsibility in various ways, such as through programs of fundamental and applied research, co-operation with the provinces in investigating and solving provincial water-use problems, and by financial assistance to the provinces for water development projects which have national or broad regional importance.

If Canada's water resources are to be developed and used wisely, then the shared constitutional responsibility for water demands a high level of co-operation — co-operation between the federal and provincial governments and co-operation among the provinces themselves.



Uncontrolled pollution of fresh water resources menaces health, stifles industrial growth and threatens our way of life . . .



. . . but an all-out assault on pollution involving all levels of society — governments, industry, universities, labour and professional groups, conservation and community associations, and concerned individuals — can undo much of the damage already done and preserve our priceless heritage of fresh water safe and sufficient for tomorrow's Canadians.



DEPARTMENT OF ENERGY,
MINES AND RESOURCES
Ottawa, Canada

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